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SYNOPSIS: A concept and preliminary design are presented for a special testing capability to be added to an existing large laboratory geotechnical testing chamber. The modified chamber is intended to allow, through comparative testing, the reasonably rigorous evaluation of methods for providing detailed information, for soil deposits, on in situ undegraded nonlinear inelastic shear stress vs strain characteristics needed for dynamic geotechnical earthquake engineering analyses. Basically, the added capability is to be a large resonant column-like torsional testing system that tests the entire chamber sample and allows access to the center of the sample for the testing of the method to be evaluated. The main features of the modified test chamber are meant to be that 1) tests of methods to be evaluated and comparative tests are to be conducted on the same sample and 2) the comparative testing method is to provide the information of interest.

INTRODUCTION

Herein, we present a concept and preliminary design for a special testing capability ("chamber testing capability") to be added to an existing large laboratory geotechnical test chamber. We also present key elements of the analysis used for this design and analysis results on which the design is based. The testing capability is being designed for the Federal Highway Administration. The modified test chamber is intended to be a means for evaluating, reasonably rigorously, under controlled conditions, testing methods for obtaining, for soil deposits, detailed information on in situ undegraded nonlinear inelastic shear stress vs strain characteristics needed for commonly used dynamic geotechnical earthquake engineering analyses (site response analyses, etc.).

The problem addressed by the modified test chamber is a difficulty that can be encountered in evaluating, through comparative laboratory testing, testing methods for providing the information of interest. The difficulty is that of conducting comparative tests that test samples that are consistent with those tested by the method to be evaluated and provide the information of interest. For example, established laboratory tests (resonant column tests, etc.; Woods, 1978) provide the needed information; however, problems can arise in preparing consistent samples that can lead to uncertainty and cloud evaluations.

CONCEPT OF CHAMBER TESTING CAPABILITY

The test chamber with the added chamber testing capability is intended to be a means for 1) testing methods to be evaluated in large, uniform, cylindrical samples of sand under controlled, but representative, conditions and 2) conducting, on the same samples, large comparative tests that provide detailed information on the idealized nonlinear inelastic characteristics of interest.

The chamber to be modified is discussed by Henke and Henke (1993) and shown in Fig. 1. The samples are 1.2 m in diameter and 0.8 m high. Tests of methods to be evaluated are conducted in the centers of the samples.

The modified chamber is shown schematically in Fig. 2. Basically, the chamber testing capability is to be a resonant column-like torsional testing system that tests the entire sample. The

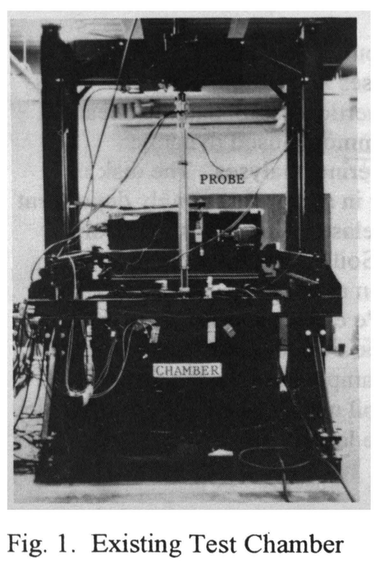

Fig. 1. Existing Test Chamber

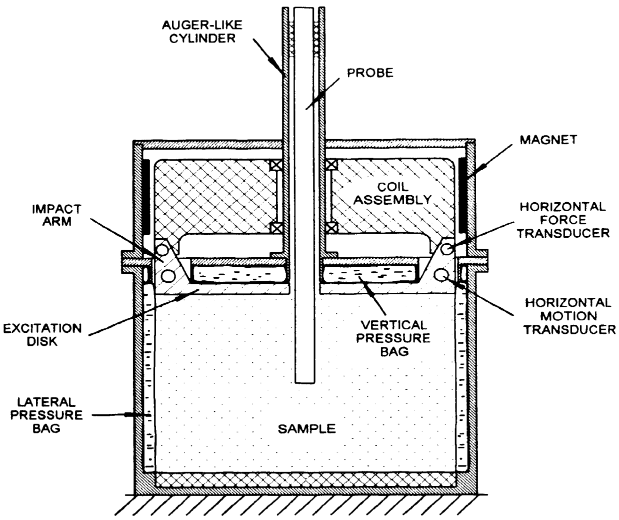

Fig. 2. Modified Test Chamber

capability is to provide, for samples, detailed information on undegraded nonlinear inelastic shear stress vs strain characteristics for low to moderately high shear strains (up to ~ 0.1%). As shown in Fig. 3, an excitation disk placed on samples is to be

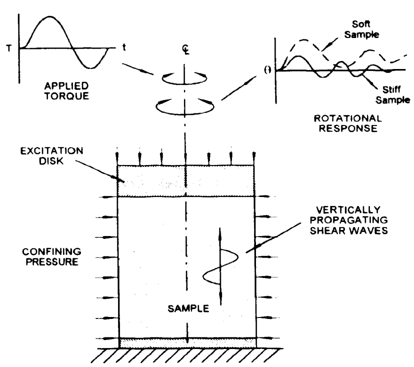

Fig. 3. Key Elements of Chamber Testing Capability

excited, at least initially, by impulsive torques. The samples are expected to develop shear stresses and strains that correspond closely to those caused by the vertically propagating shear waves that are described by commonly used dynamic geotechnical earthquake engineering analyses. The disk is expected to respond by rotating in a manner strongly dependent on the undegraded nonlinear inelastic shear stress vs strain characteristics of the test soil. Soil characteristics are to be inferred from torque and rotation related measurements by simulating tests analytically. We expect to be able to conduct tests using both the method to be evaluated and the chamber testing capability on the same sample because the former is expected to act largely on the soil near the center of the sample while the opposite is true for the latter.

With respect to details, impulsive torques are to be created by an impulse device consisting of four separate coil-magnet assemblies spaced equally around the periphery of the excitation disk. To activate the device, an energized capacitor is to be discharged into the coils. The resulting impulsive torque is to be transmitted to the disk through short arms extending vertically from the disk. Values of torque are to be derived from forces measured using horizontally oriented force transducers placed between the arms and the impulse device. Values of the rotation of the disk are to be derived from linear motions measured using horizontally oriented motion transducers placed along its periphery.

KEY ELEMENTS OF ANALYSIS

Key elements of the analysis used to develop the preliminary design for the chamber testing capability are shown in Fig. 4. The analysis simulates tests to be conducted using this facility. Solutions are obtained numerically for a selected sequence of times.

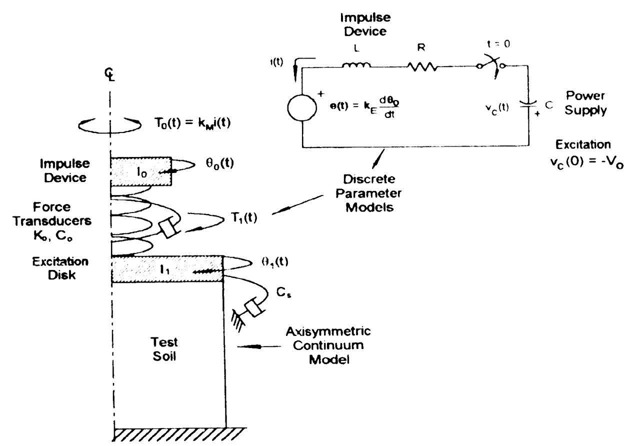

Fig. 4. Model for Analysis for Chamber Testing Capability

The model for a test includes a rigid disk with mass attached to an axisymmetric cylindrical continuum representing the test soil. The disk is excited torsionally by a torsional spring-mass-damper system that represents the mechanical elements of the impulse device. The spring models the torsional flexibility of the force transducers. The model also includes a coupled electrical component that describes the behaviors of key electrical elements of the excitation system. The excitation consists of an initial voltage across a capacitor, which models the source of impulsive power. The only stresses and strains described for the continuum are shear stresses and strains.

The dynamic behaviors of the electrical component, the impulse device, and the disk are described using discrete parameter models that are linear. Corresponding solutions are obtained following, in principle, the incremental procedure presented by

Clough and Penzien (1975). The dynamic behavior of the test soil is modeled using a multi-dimensional axisymmetric continuum approach (Henke, et al., 1982; Henke, et al., 1983) that is similar, in concept, to the method of characteristics as applied for one-dimensional conditions (Streeter, et al., 1974). For the preliminary design presented herein we assumed linear elastic behavior for the continuum. Viscous damping of the continuum was modeled by a discrete parameter element, C_s, attached to the disk; the continuum approach used does not describe viscous damping. Nonlinear soil behavior corresponding to higher levels of loading was described by using a reduced elastic modulus and an increased level of viscous damping, each roughly consistent with the level of strain developed.

Herein, we present only the equations involving electrical parameters since the electrical component is, in essence, the only new element of the analysis. These equations are

$$L\frac{di^2}{dt^2} + R\frac{di}{dt} + \frac{1}{C}i = -k_E\frac{d^2\theta_o}{dt^2} \quad (1)$$

$$I_o\frac{d^2\theta_o}{dt^2} + C_o\left(\frac{d\theta_o}{dt} - \frac{d\theta_1}{dt}\right) + K_o(\theta_o - \theta_1) = k_M i \quad (2)$$

The symbols are defined in Fig. 4. The parameters k_E and k_M are electrical and mechanical constants that may be derived readily from physical principles (Smith, 1976). Equation 1 is a form of Kirchhoff's voltage law for the electrical circuit. Equation 2 represents Newton's second law of motion for the torsional impulse device. The initial conditions are

$$v_c(0) = -V_o \ ; \quad i(0) = 0 \ ; \quad \frac{di}{dt}(0) = \frac{V_o}{L} \ ; \quad \frac{d^2i}{dt^2}(0) = -\frac{RV_o}{L^2} \quad (3)$$

$$\theta_j(0) = 0 \ ; \quad \frac{d\theta_j}{dt}(0) = 0 \ ; \quad \frac{d^2\theta_j}{dt^2}(0) = 0 \quad (4)$$

MODELS FOR ANALYSES

The following values were used for the parameters of the discrete parameter models: $k_M = k_E = 18.945$ Wb, $I_o = 10.0$ N-s²-m, $K_o = 2.6 \times 10^8$ N-m/rad, $C_o = 5100$ N-m-s, $I_1 = 43$ N-s²-m, L = 0.01624 H, C = 0.27 f, and R = 0.4 Ω. The value of K_o was derived based on the reported stiffness of an appropriate force transducer. The value of C_o corresponds to a damping ratio of 5%. The values for the electrical parameters were obtained based on physical principles and trial and error using the analysis described above.

With respect to the continuum model, we considered a sample of medium dense sand subjected to a representative confining pressure of 69 kN/m². We conducted two analyses, one for a high and one for a low level of loading. The high level is one for which nonlinear stress vs strain behavior was predicted over a large portion of the sample (in particular, the outer portion which has the largest effect on behavior in torsion). The level was such that a shear strain of 0.1% was computed at a radius of two-thirds of the radius of the disk, r_o. This required an excitation voltage of 220 v. The following values were specified for soil characteristics: density, ρ, = 1664 kg/m³, secant shear modulus, G, = 1.25×10^7 N/m², and C_s = 12,190 N-m-s. The values of G and C_s are consistent with the strain of 0.1%; the value of G corresponds to a value of $G/G_o = 0.174$ (G_o = low strain shear modulus) while the value of C_s represents a damping ratio of 26%. These values were based on results from tests conducted previously in the chamber (Henke and Henke, 1993). The low level of loading is the highest level for which linear elastic behavior was predicted throughout the sample. The level was such that a maximum shear strain of 0.001% was computed for the outer radius of the sample, where strains are generally greatest. The required excitation voltage was 7.5 v. The following values were specified for soil characteristics: G_o = 71,850 kN/m² and C_s = 2140 N-m-s. The value of C_s represents a damping ratio of 2%.

RESULTS OF ANALYSES

Relevant analysis results are presented in Fig. 5. Figures 5(a), 5(b), and 5(c) show, for each level of loading, the torque applied

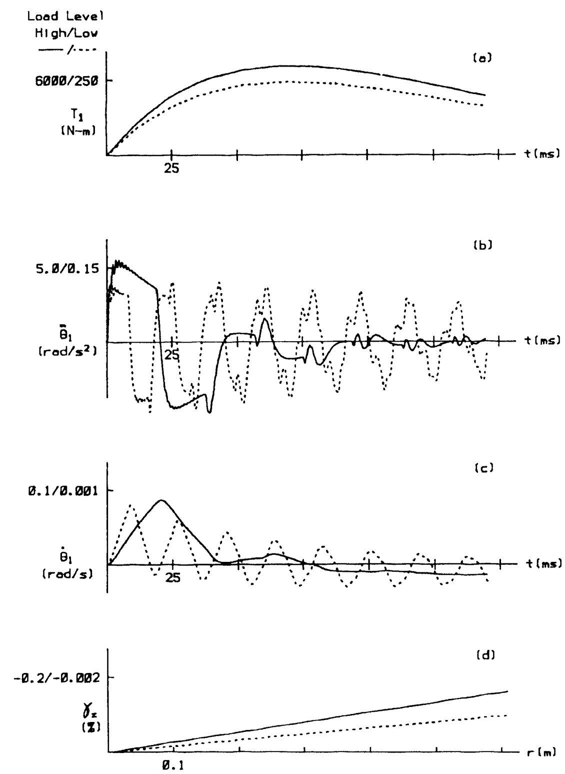

Fig. 5. Results from Analyses; See Fig. 4 for Definitions of Symbols

to the disk, T_1, and the angular acceleration and velocity of the disk, $\frac{d^2\theta_1}{dt^2}$ and $\frac{d\theta_1}{dt}$, as functions of time. As would be expected, the values of these variables are much larger for the high than for the low level of loading and the motions show lower frequencies at the high level of loading than at the low level. Figure 5(d) shows, for each level of loading, the maximum shear strain within vertical cylindrical surfaces, γ_z, as a function of radius for the continuum at the disk. As would be expected, the values of strain are much larger for the high level of loading than for the low.

PRELIMINARY DESIGN

The following are preliminary design requirements based on the analysis results presented herein: excitation voltage, 7.5-220 v; horizontal force applied by each coil, 100-3000 N; linear horizontal acceleration and velocity of the disk at its outer radius, 0.05-3 m/s^2 and $5x10^{-4}$-0.05 m/s; and frequency, 0-1000 cps.

With respect to the preliminary design, each magnet, 0.3 m x 0.1 m x 0.025 m, is to create a magnetic field having a flux density of 0.175 Wb/m^2 at the outer surface of the associated coil. Each coil is to have 150 turns and is to carry a maximum current of 375 A. The total inductance of the four coils was estimated to be 0.01624 H. A capacitance of 0.27 f and resistance of 0.4 Ω were found to give satisfactory simulations. The transducer model selected for measuring the horizontal force to be applied by each coil is a Transducer Techniques, Inc. model LB-1K axial force transducer having a capacity of 4500 N and natural frequency of 32,000 cps. This transducer measures only compression; therefore, two will be needed for each coil. Because computed accelerations are rather low, we selected a velocity transducer for measuring the motion of the disk. The transducer model selected is a Trans-Tek, Inc. model 0100-0000 velocity transducer having a sensitivity of 47.2 mv/(cm/s) and a frequency response of 1500 cps.

CONCLUSIONS

A concept and preliminary design have been presented for a special testing capability to be added to an existing large laboratory geotechnical test chamber. The modified facility is to be a means for evaluating, reasonably rigorously, by comparative testing, geotechnical testing methods for providing, for soil deposits, detailed information on in situ undegraded nonlinear inelastic shear stress vs strain characteristics needed for commonly used dynamic geotechnical earthquake engineering analyses.

The main features of the modified test chamber are intended to be that

1) the chamber is to allow comparative tests to be conducted on the same large, uniform samples tested by the methods to be evaluated and

2) the comparative testing method is to provide the information of interest.

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